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TIME-KEEPING IN PARIS.

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From The Popular Science Monthly, January, 1882.

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EDMUND A. ENGLER.

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MANY of the discoveries of science which at the time are regarded merely as refinements — very interesting, but without practical value — sooner or later find their special uses in supplying wants before unfelt. It is but one of the evidences of the advance of civilization that exact methods of dividing and measuring time are now in demand, not only by scientists and professional men as formerly, but by persons in the most ordinary pursuits of life. To railroad men and watch-makers as a matter of necessity, to manufacturers and business men as a matter of economy, and to individuals as a matter of convenience, it has come to be highly important to know what is the exact time of day to the second, in circumstances where half a century ago it would have quite sufficed to know the minute or even the hour. This may be due to the increased value of time when measured by the number of events or the magnitude of operations which modern ingenuity is capable of crowding into a given interval; there can be no doubt that a second to-day records a greater stride in the world's progress than did many hours in the days of our ancestors. Of so great importance, for many evident reasons, has the knowledge of the exact time become, that much thought of some of the best heads has been devoted to methods of ascertaining it and making it available by distribution for public use.

The methods of obtaining the exact time by astronomical observations have long been well established, and are, except in minor details, the same in all parts of the world. It will here be sufficient to say, in explanation of the usual method, that time is determined by observing the transit, over the meridian, of stars — or other heavenly bodies — whose position is known by previous calculation verified by repeated observation. The difference between the time of the calculated meridian passage and the time indicated by the clock when the star was observed to pass the meridian is the error of the clock. The face-

reading of the clock at the instant of transit corrected for this error is the exact time at that instant.*

But experience has shown that no clock, however fine its mechanism, will run without change of error; so that, although for a particular instant the error of a clock is known by astronomical observation, it is by no means certain what will be its error for any subsequent instant. Its error for this instant can be determined with precision only by another observation. An approximation to its error at any instant can, however, be obtained by simple calculation, based upon two assumptions: First, that the change in error between the last two (or any previous two) observations was uniformly distributed over the interval of time between those observations, thus making it possible to determine a rate of change; second, that the rate of change in error since

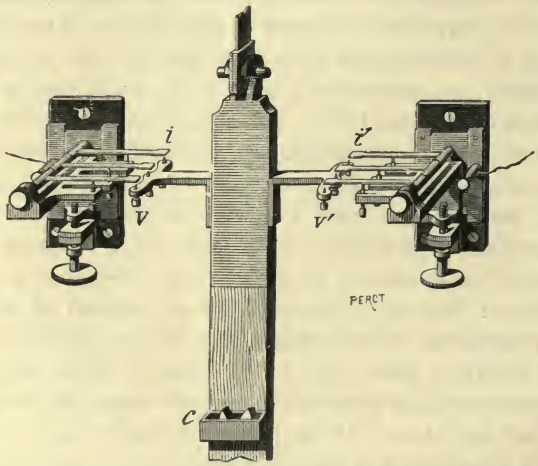

FIG. 1. — REGULATOR OF PARIS OBSERVATORY — PENDULUM CONTACT-PLATES.

the last observation has been uniformly the same as during the previous interval. The reliability of this approximation is evidently entirely

* It is, perhaps, needless to say that the operation of taking time by the transit instrument is really far more complicated than would appear from the description above; but the difficulties arise only from mechanical or physical imperfections, or from uncertain or changing conditions. Thus, corrections must always be made in nice work for errors in the instrument or its setting — such as the level, azimuth, and collimation corrections — for personal equation of the observer, and for aberration; these corrections, however, only aid the observer in ascertaining the exact instant when the star actually crossed his meridian and do not in any way affect the principle already given. For a full account of the methods of making these corrections, the reader is referred to Chauvenet's "Astronomy."

dependent upon an empirical knowledge of the clock. Cloudy weather sometimes makes this method the only resource.

In order that a clock should be used as an indicator of time, it is not enough that its error at every instant should be known; its error must be continually corrected, so that its face-reading shall always indicate true time. And in order that a clock should be used as a distributor of time, it must be provided with apparatus, distinct from the mechanism which keeps the time and in no way interfering with it, which is capable of sending time to other clocks. The methods and instruments in use in Paris for the accomplishment of these two objects will be described in this paper.

At the Paris Observatory a very fine standard clock or astronomical regulator is kept running on correct mean time by transit observations, being provided with the most approved self-compensating apparatus, and being further corrected daily by the adjustment of weights to the pendulum. For the latter purpose the pendulum-rod is provided with a box, *c* (Fig. 1), for holding small weights, these are made of such shape that they can be easily put into the box or taken out by means of a small pair of pincers without in any way affecting the running of the clock. The box being placed above the centre of oscillation of the pendulum, the addition of a weight makes the clock go faster and the removal of a weight retards it. By repeated experiment it has been ascertained what change each weight, under given conditions of atmospheric influences, will produce in a given time; so that the operator knows how to adjust the weights in every case, and the clock can be kept running on mean time with the greatest attainable accuracy.

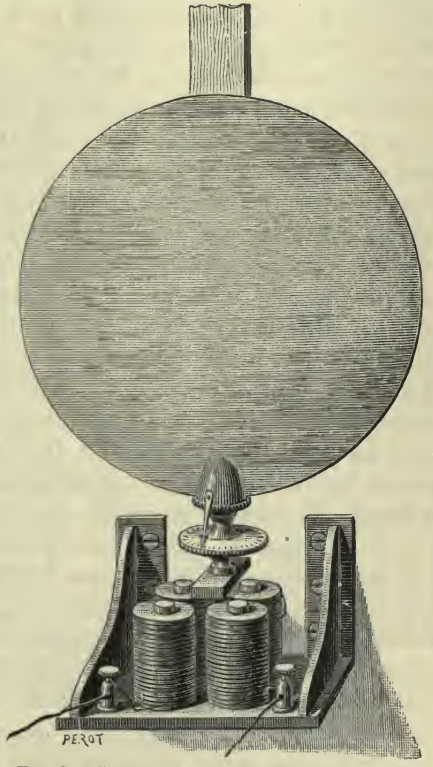

FIG. 2. — PENDULUM OF SECONDARY CLOCK.

This clock, beating seconds, closes for, say, one-half second during

each vibration an electric circuit along the line of which the secondary clocks are situated. This is done by means of the apparatus shown at the top of Fig. 1. To the upper end of the pendulum-rod are attached arms, V and V', which alternately raise the levers, i and i', as the pendulum vibrates, thus closing the contact of the electric circuit, one wire of which reaches the arms V and V', while the other is attached to the levers i and i'. There are three levers at i and i', and three contact points on the arms V and V', in order that the transmission of the current need not depend upon a single contact which some trivial circumstance — as, for example, the lodging of a grain of dust — might prevent.

The current thus transmitted is carried along wires placed in the city drains to the secondary clocks, which are controlled by the regulator at the observatory, as shown in Fig. 2; but the motive power of each is a weight operating as in ordinary clocks. To the foot of the pendulum of each secondary clock is attached a piece of soft iron, which swings just above the poles of two electro-magnets in the circuit of the observatory clock. The operation is as follows: The secondary clocks are kept running with a very small gaining rate. At each vibration of the pendulum of the observatory clock the circuit is closed, and a current passes from a battery of six Daniel cells and magnetizes one of the electro-magnets at the foot of the pendulum of each secondary clock, which, attracting the piece of soft iron, retards its motion. The adjustment is delicately made, so that the retardation is just sufficient to keep the secondary clocks beating synchronously with the observatory clock.

This system, in Paris the device of M. Breguet, is a modification of the Jones system, which is considered by scientists the best ever invented for regulating clocks at a distance from the standard clock. Its main advantage lies in the fact that by no disaster to the wire of the circuit or to the regulator of the system can the secondary clocks be stopped. Should, by any accident, the wire be broken or the observatory clock stopped, the secondary clocks move right on, only slightly too fast; whereas, in any system of dials which are driven by a standard clock, any such mishap must of necessity stop the dials, whereby those depending upon them for time are misled, if not entirely deprived of time. In point of accuracy the results in this system are, indeed, all that could be desired, the error of the secondary clocks being kept less than one-tenth of a second; but, because the secondary clocks must be fine time-keepers, the system is quite expensive. The estimated cost of each of these clocks is from 2,400 to 2,500 francs, or from $480 to

$500. On the two circuits, each terminating at both ends at the Observatory of Paris, there are distributed thirteen clocks, the farthest being

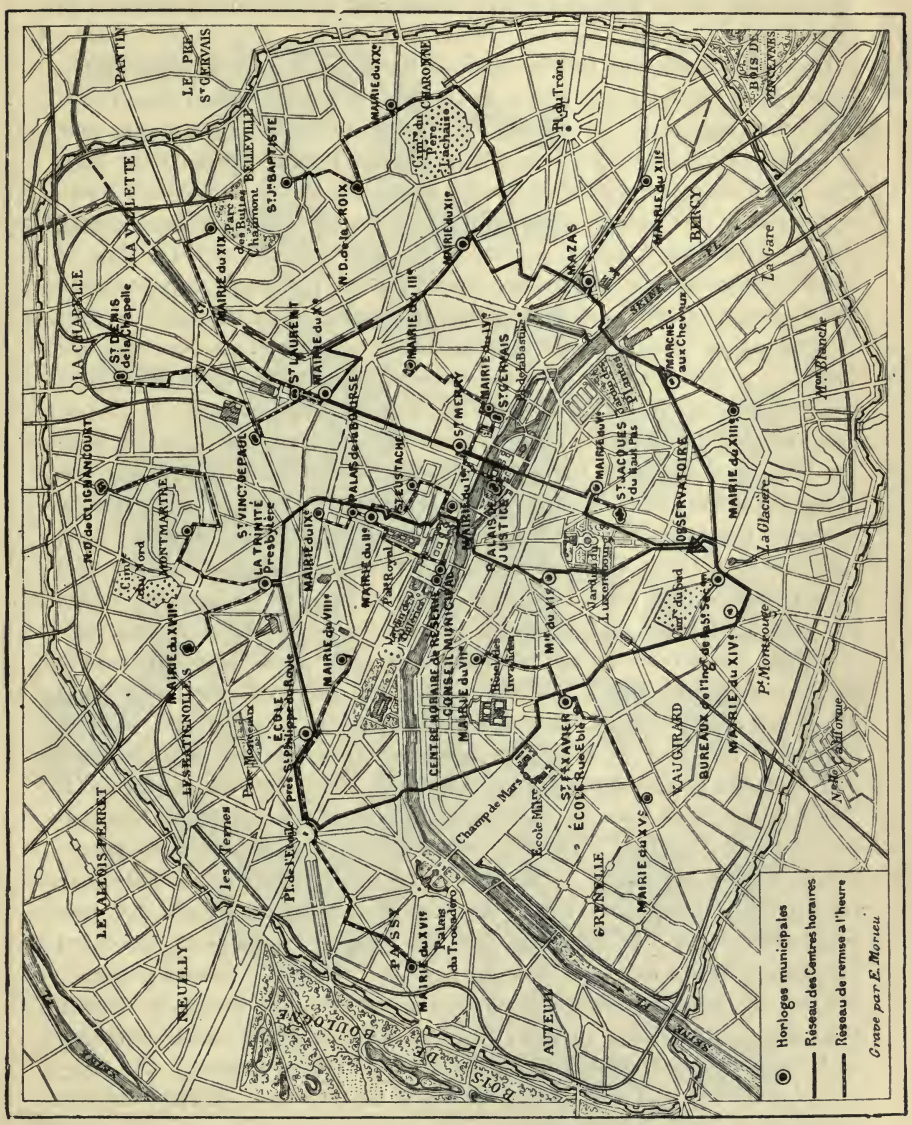

FIG. 3. — MAP OF PARIS. The two circuits from the Observatory are represented by heavy black lines; the lines from the "horary centres" are represented by dotted lines.

at a distance of seven and a half kilometres, or nearly four and a half miles from the observatory. The clocks are furnished with second-

hands, and are placed so that they can be easily seen from the street, and usally in prominent positions. The system is entirely under municipal management and has been in successful operation for about four years.

But the system thus far described is the basis of a much wider distribution of accurate time; for each of the secondary clocks is itself provided with apparatus by means of which it sends a signal every hour to clocks placed on special circuits and to the public clocks of the city. For this reason the secondary clocks have come to be known as "horary centres." The methods employed for the distribution of the hourly signals from the "horary centres" are not uniform, nor are they of equal importance or extension; some of the principal watch-makers have invented methods of their own for special services, which are not of general interest, but the system which radiates from the "horary centre" at the Hôtel de Ville (at present the Tuileries) to the twenty *mairies* of Paris is worthy of mention here both on account of its importance and ingenuity. There is a system of telegraph-wires connecting all the *mairies* of the city with the Prefecture of the Seine; the regulator at the Hôtel de Ville automatically sends a current into twenty relays at precisely one hundred seconds before the end of each hour, and thus cuts these wires off from their ordinary telegraphic duty and places them in the circuits of the different *mairies*. Then, at twelve seconds before the end of the hour, the regulator sends another current into the circuit of the *mairies;* this current is stopped precisely at the end of the hour. At each *mairie* the clock automatically shuts off the wire from the telegraph and connects it with the electromagnet of the clock at sixty-five seconds before the end of each hour, and reverses the operation at five seconds after the end of the hour. Ten seconds after the end of the hour the first current from the regulator at the Hôtel de Ville automatically stops, and the wires are restored to the telegraph. The clocks at the *mairies*, being thus corrected every hour, run with very small error; but, should for any reason the error become large, or the clock stop, this is indicated automatically by the fact that the current from the "horary centre," instead of stopping precisely at twelve o'clock, continues for thirty seconds. By this, the operator at once knows that his clock is wrong, and can have it set right. From the other "horary centres" the number of lines is in no case larger than six, the lines are shorter, and the apparatus accordingly simpler.

But there is another novel and ingenious method for the distribution of time in use in Paris, which, though lacking in accuracy sufficient for

scientific purposes, has both convenience and economy to recommend it for general uses, and for that reason has become quite extensively employed in a short time. Abandoning electricity as an uncertain means

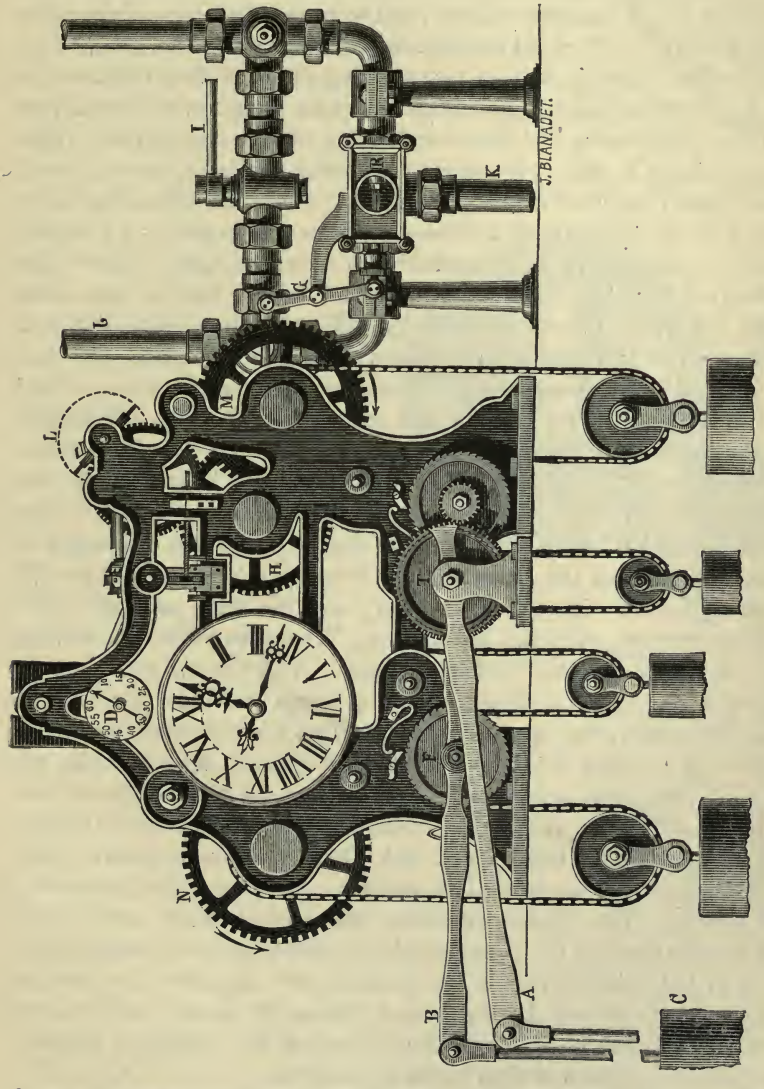

FIG. 4.—DISTRIBUTING CLOCK OF THE PNEUMATIC SYSTEM.

for moving clock-work at a distance, the inventors of this system, Messrs. Popp and Resch, have accomplished the same object by the use

of compressed air, and for this reason have called their clocks "pneumatic clocks." They were exhibited at the Exposition at Vienna in 1875, and are now widely distributed in that city.

The essential parts of the system are three: 1. Machinery whose function it is to compress the air, and to propel impulses of the same every minute; 2. Pipes led through the streets and into the houses; 3. Dials provided with mechanism for receiving the pneumatic impulses.

1. At a central point a steam-engine drives pumps which compress air to five atmospheres in a reservoir holding eight cubic metres. This compressed air is sent, by means of a special regulator, into a second receiver called the "distributing reservoir," where the pressure is kept constant at seven-tenths of an atmosphere, or a little less — a pressure determined empirically to be sufficient to move the dials. The "distributing reservoir" is opened to transmit an impulse into the pipes each minute, for about twenty seconds, by a distributing clock (Fig. 4). This consists of two distinct movements. The one to the left, provided with balance-wheel, counter-weights, etc., is simply an ordinary clock, and indicates the hour, minute, and second, as shown in the figure. The movement to the right is contrived especially for moving the distributing valve, R. This valve, ingeniously arranged in such a way that the pressure acts only on a minimum of its surface, is inclosed in a valve-box and has three orifices. The first of these puts the valve in communication with the "distributing reservoir;" the second puts it in communication with the street-pipes; and the third puts the pipes in communication with the atmosphere. The first orifice is always open; the other two are normally closed. The automatic escape of the lever G, at the end of each minute, moves the slide-valve, opens the second orifice, and sends an impulse into the pipes; at the end of a number of seconds, determined by experience and dependent on the length of the pipes (a number which varies from ten to fifteen seconds), the slide-valve is brought back to its original position by the clock-work, closes the two orifices, and allows the extra pressure which has been introduced to escape into the air. This operation is repeated every minute. The motive-power for the clock-work of both movements is furnished by the compressed air, which automatically lifts the pistons in the cylinders, C, at the end of each minute. The pistons move the levers B and A; the first of these, B, winds up the counter-weights as much as they have fallen during the preceding minute; the second, A, imparts motion to the slide-valve.

2. The impulse given by the clock-work is distributed through the

city by means of pipes laid like ordinary gas-pipes. In the streets the pipes are of iron, and have a diameter of twenty-seven millimetres (about one inch); but in the houses the pipes are of lead, and of different sizes — the diameters being fifteen, six, or three millimetres (practically one-half, one-quarter, or one-eighth of an inch), depending on the number and size of the dials to be operated. These pipes are entirely hidden from view, and in no way interfere with the appearance of the dials.

3. The mechanism of each dial, whatever the size, is shown in essential part in Fig. 5. A leather or rubber flap, seen in the cylinder, receives the impulse as it comes from the pipe and moves a piston, which acts upon a lever-arm arranged by simple connections to move the minute-hand one space forward. The ordinary clock-gearing (not shown in the figure) secures the proper motion for the hour-hand. This part of the apparatus can be inclosed in any case — as plain or as ornamental as desired. The cases are made in all the designs and sizes of ordinary clocks, and appear precisely like them, except that the minute-hands jump suddenly over one space at the end of each minute, and remain stationary during the minute, instead of moving gradually over the space.

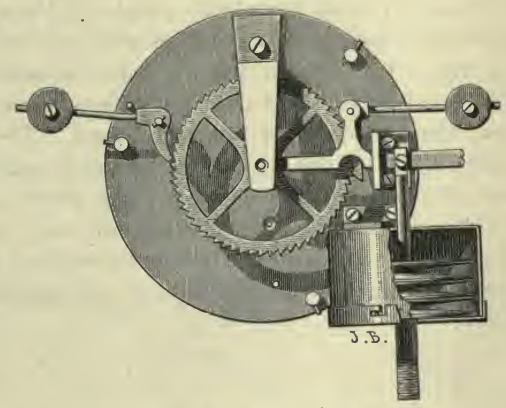

FIG. 5. — MECHANISM OF A PNEUMATIC DIAL.

All the machinery of the system is in duplicate, for use when repairs are needed. Delicate manometers indicate the pressure at all times, and the most approved electric apparatus is used to indicate the particular point at which a defect has occurred. A skilled engineer is on the watch at all times. Provision is also made so that, in case of any interruption in the regulator, the dials may be run by hand. Accuracy of time is secured by daily comparison with the observatory clock.

Excellent as the system is for general uses, the pneumatic dials cannot be used for accurate time-work, because it requires in the extreme case — namely, for a distance of twenty thousand metres — at least ten

seconds for the impulse to reach its destination. Thus it will be seen that each dial is slow a certain number of seconds, depending upon its distance from the central station; nor has it been found that the error of any particular dial is constant. But the error will never be allowed to exceed ten seconds. Should the extension of the system require it, Paris will be divided into six districts (surveyed so that no point in the city shall be over twenty thousand metres from a central station), each provided with its central station equipped in other respects as the one described, but all receiving their compressed air from a common reservoir centrally located.

However, there are plenty people in Paris, as there are, doubtless, in every city, for whom a time even ten seconds in error is accurate enough. The system was put into operation there about March 15, 1880, and in the first four months there were fifteen hundred subscribers, distributed in six hundred houses. The popularity of the pneumatic clocks is due to their convenience and cheapness. The rental is only five centimes (one cent) per day for the first clock; four centimes (eight mills) per day for the second clock; three centimes (six mills) per day for the third and every subsequent clock rented by the same person; and the expense of pipes and apparatus is borne by the company.

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